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Critical Literature Review
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Fisheries Management and Ecosystem Monitoring in the Southern Ocean

Toni Wi

Student ID: 56617477

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Abstract:

The Commission for the Conservation of Marine Living Resources, otherwise known as CCAMLR, is the governing body established as part of the Antarctic treaty system to regulate fisheries in the Southern Ocean. Due to concern about the exploitation of Antarctic krill (*Euphasia superba*), a key prey item in the Antarctic marine food web, the CCAMLR Ecosystem Monitoring Programme (CEMP) aims to account for the needs of predator species when setting conservation measures such as catch limits. This precautionary approach is integral to the conservation objectives of CCAMLR and the rational use of marine resources. Predator parameters and environmental conditions are monitored as they are likely to be important for both predator and prey species. In the krill fishery, a krill yield model allows for krill escapement and trigger levels are set to protect dependent predators and minimize ecosystem effects. The scale of management units should be taken into account for a better understanding of the effects of harvesting and allow for faster management response. Future challenges such as climate change could further complicate the ecosystem based approach, but may be anticipated by the precautionary management of CCAMLR and the ecosystem monitoring programme.

Introduction

The Southern Ocean brings to mind images of vast stretches of untouched open water teeming with wildlife. But in reality the ocean surrounding Antarctica is far from untouched, and has witnessed its fair share of exploitation. Fishing and the extraction of biological resources can have profound effects on marine ecosystems (Ainley & Pauly, 2014). One pattern of marine resource extraction known as 'fishing down the food web' describes how larger species are targeted first, and when numbers decrease, species with a lower trophic position are fished instead (Pauly, Christensen, Dalsgaard, Froese, & Torres, 1998). This leads to the development of the marine trophic index, when the tropic level of the catch is reduced (Pauly, Watson, & Alder, 2005).

Exploitation in Antarctica started with species that occupied a high trophic level in the food web, such as marine mammals and large fish (Ainley & Pauly, 2014). Sealing began in the subantarctic islands in the late 1700's and proceeded through a boom and bust cycle of exploitation and extirpation (CCAMLR, 2015b), which was followed by a similar cycle for whaling (Constable, de LaMare, Agnew, Everson, & Miller, 2000). Finfishing began in South Georgia in the season of 1969/1970 and the season after at Iles Kerguelen. The target species of marbled notothenia (*Notothenia rossii*) was overfished, leading to a switch to different species (Kock, Reid, Croxall, & Nicol, 2007). The fishery for mackerel icefish (*Champsocephalus gunnari*) was more resilient to fishing on a large scale, but still suffered from collapsing catches in the Atlantic Ocean sector (Kock et al., 2007). It was due to disappearing fish stocks in Antarctic continental waters that industry focus switched to Antarctic krill, *Euphasia superba*.

In 1977, the Antarctic Treaty Consultative Parties began negotiation on a convention in response to concern about the exploitation of Antarctic Krill (Constable et al., 2000). Krill is considered a key species in the Antarctic food web, as it re-packages primary production by grazing on phytoplankton, making energy available for other predators (CCAMLR, 2015b). In order to avoid patterns of exploitation preventative action was needed, not only to sustain the krill fishery, but to also regulate krill populations to ensure the recovery of whale and seal populations that had been close to extinction (Constable et al., 2000). It was concern about exploitation and consequences for the marine ecosystem that led to the Convention on the Conservation of Antarctic Marine Living Resources (CCALMR, 2015), which was signed in 1980 and came into force in 1982.

In this review management of fisheries in the Southern Ocean will be discussed with particular reference to ecosystem monitoring as part of an ecosystem approach. A further investigation into CCAMLR and the Ecosystem Monitoring Programme will be followed by a review of key predator species, with specific emphasis on the krill fishery. Finally, the future outlook for ecosystem based management in Antarctica will be assessed in light of the challenges posed by environmental change.

CCAMLR and the Ecosystem Monitoring Programme

The Commission for the Conservation of Antarctic Marine Living Resources, otherwise known as CCAMLR, was established to put the Convention into practice by developing rules for managing fisheries in Antarctica (Agnew, 1997). The area of influence for the Convention is the entire zone south of the Antarctic Polar Front, and the aim of the Commission is to enable both harvesting of marine species and maintenance of conservation principles (Constable et al., 2000). The core principles of the Convention are contained within Article II, paragraph 3, and are briefly:

a) The decrease in size of a harvested population to below levels which ensure stable recruitment should be prevented
b) Ecological relationships between harvested, dependent, and related populations of Antarctic marine resources must be maintained and depleted populations restored
c) Risk of irreversible ecosystem change is prevented or minimized with the aim of sustained conservation of resources

Article IX states that the Commission must base their decisions on the best scientific evidence, and that controls on fisheries are through conservation measures, which are binding to signatories of the Convention, and resolutions, which are non-binding but agreed principles (Constable et al., 2000). Decision-making in CCAMLR is based on consensus (Parkes, 2000), which can prove difficult with contrasting interests of different parties.

Current fisheries under the Convention area are for Patagonian toothfish (*Dissostichus eleginoides*), Antarctic toothfish *(Dissostichus mawsoni*), Antarctic krill *(Euphasia superba*), and mackerel icefish (*Champsocephalus gunnari),* with five different stages of fisheries recognized, ranging from new, exploratory, established, lapsed, and closed (CCAMLR, 2015d). Fisheries are managed under a precautionary approach, which was developed as a way to meet the objectives of Article II of the Convention and better take into account uncertainty, especially in regards to the krill fishery (Constable et al., 2000). Reactionary management, where action is taken when it is needed, was deemed non-viable as a long-term strategy, and in lieu of the preferential feedback management a precautionary approach was recommended (Constable et al., 2000).

Parkes (2000) notes that the precautionary approach and the ecosystem approach underpin the principles outlined in Article II, in that the precautionary approach is needed to avoid decisions with a high risk of long-term effects, and the ecosystem approach ensures that fishing effects are limited to a level that is unlikely to have a major impact on predators of the target species. Also noted is the term 'rational use' in the Convention, which implies that fishing need not be delayed until all impacts have been assessed, but a precautionary approach should take some account of uncertainty. Interestingly, Constable (2011) interprets the term 'rational use' as activities that comply with maintenance and sustainability of the amenity of the oceans. Even though there are different interpretations of 'rational use', they share the core principle of maintaining the structure and function of marine ecosystems while allowing for controlled resource extraction. This encapsulates the dual function of CCAMLR, and perhaps suggests that resource use and conservation are not mutually exclusive.

The CCAMLR Ecosystem Monitoring Programme (CEMP) was established using ideas gained from studies on environmental impact assessment, where a baseline study predicts effects and a monitoring study observes the actual effects after a particular project (Agnew, 1997).

By using predators as indicators of prey availability, a framework was developed using ecosystem monitoring as part of fisheries management (Agnew, 1997).

Management exerts control on harvesting, which impacts the environment, which links back to the monitoring programme in a feedback loop (Agnew, 1997). Collection of data follows a set of standard methods and is submitted voluntarily by member countries (Kock et al., 2007). A set of key critical species was compiled with the understanding that monitoring the entire ecosystem was impractical, and restricted therefore to select predators and certain areas (Constable et al., 2000).

The aims of the CEMP are to:

i. Detect and record changes in critical components of the marine ecosystem as a basis for the conservation of Antarctic marine living resources
ii. Distinguish between changes due to harvesting of commercial species and changes due to physical and biological environmental variability

To meet the first aims, parameters of abundance, distribution, reproduction, feeding, growth, and condition are collected for key predators of the target species. The second aim is more difficult, and requires the monitoring of prey species, predator species, and environmental factors, as well as the links between them (Parkes, 2000). To account for difficulties owing to high ecosystem complexity, a strategic modelling approach has been adopted by CCAMLR, whereby simple computer models capture important components and linkages, rather than a comprehensive ecosystem model (Parkes, 2000).

Fisheries management is reviewed annually by the Scientific Committee with specialist working groups as well as an international scientific observation scheme providing up-to-date scientific information (CCAMLR, 2015a). Agnew (1997) makes the point that having two different working groups, one on krill and one on CEMP, slowed progress on developing feedbacks between the results of CEMP and the setting of regulatory conservation measures to manage the krill fishery. Only once both groups were integrated into the Ecosystem Monitoring working group was progress made incorporating CEMPT into fishery management. This highlights the need to bring together the various strands of information when dealing with ecosystems and predator-prey interactions.

Predators and food webs

The ecosystem approach manages the effect of removal of a target species on the ecosystem. In order to do so the monitoring of key predator species must be undertaken as indicators of the effects of removal of a prey species on linkages within an ecosystem. Critical prey species for the CCAMLR Ecosystem Monitoring Programme are species that occupy key positions within the Antarctic marine ecosystem and are potentially harvestable, such as Antarctic krill, Antarctic silverfish (*Pleuragramma antarcticum*), Crystal krill (*Euphasia crystallorophias*), and early life stages of fish (Constable, 2011). Predator selection was based on the species having a wide geographic distribution, sufficient data to construct a baseline for monitoring, and the proviso that they fed almost exclusively on the target prey species, as well as being an important component of the ecosystem (Constable, 2011). The predator list includes crabeater seals *(Lobodon carcinophagus*), Antarctic fur seals (*Arctocephalus gazella*), Adélie penguins (*Pygoscelis adeliae*), chinstrap penguins *(P. antarctica*), gentoo penguins (*P. papua)*, maracroni penguins (*Eudyptes crysolophus*), Antarctic petrels (*Fulmaris glaciodies)*, cape petrels (*Daption capensis*), and black browed albatross (*Diomeda melanophris*) (Agnew, 1997).

As well as predator parameters, environmental conditions such as changing sea ice and sea surface temperatures are also monitored, as they are likely to be important for both predator and prey species and the interactions between them (Agnew, 1997). Monitoring protocols are being developed for predator parameters such as local weather and penguin survival and recruitment, but there are no Standard Methods for prey parameter monitoring except for prey availability and predator interactions routinely monitored by the Secretariat of CCAMLR (Agnew, 1997).

In the case of the krill fishery, management procedures for predators presented to the Scientific Committee are based on the maintenance of predators via krill escapement (75%

of pre-exploitation level), predator abundance (50% of pre-harvesting of prey), and annual predator productivity (80% of pre-exploitation level) (Constable, 2004). These objectives are 'bottom-up' and 'top-town' targets that aim to satisfy the requirements of the food web when fisheries have removed production from the ecosystem (Constable, 2004).

Increasing interest in the krill fishery from both CCAMLR member and non-signatory countries is due largely because of the demand for krill in aquaculture feed and for use in dietary supplements such as Omega-3 krill oil (Kock et al., 2007; Trivelpiece et al., 2011). In previous years (2010-2014), eight CCAMLR members have targeted krill, with 58% of the catch taken by Norway, 19% by the Republic of Korea, and 10% by China (CCAMLR, 2015c). The krill fishery is the largest in the Southern Ocean by tonnage at more than 200,000 tonnes, with catch limits over 8.6 million tonnes (Nicol, Foster, & Kawaguchi, 2012).

In 1990, CCAMLR endorsed the setting of catch limits for krill in order to minimize over-exploitation and the effects on krill-dependent predators, with the first catch limit set in 1991 (Kock et al., 2007). A three-part decision rule was developed to take predator requirements into account and determine the proportion of the population of krill that could be harvested with minimal risk on an annual basis (Kock et al., 2007). A numerical factor (y) is used along with an estimate of biomass from a pre-exploitation survey to then estimate a potential sustainable annual yield (Parkes, 2000). This yield estimate was then intended to be revised as methodology was improved and new information on biomass and other biological parameters came to hand (Kock et al., 2007). The level of krill escapement, set at 75%, represents a midpoint between not taking account of predators and only allowing for a 50% escapement level in the case of a single-species fishery, and providing complete protection for predators, or not having a fishery at all (Constable, 2011). This target value has potential to be refined in future development of the model (Parkes, 2000).

In order to interpret the response of ecosystems to the krill fishery various different models have been created to simulate interactions between ecosystem components, and Agnew (1997) notes that model validation is essential, and may be done using CEMP data. However, the suggestion of experimental fishing that would essentially 'force' a response from the ecosystem, such as intensive fishing in one area while monitoring predator and prey responses, should be approached with caution as it does not seem to adhere to CEMP objectives. Also, temporal and spatial variability must be accounted for in models, such as predators switching prey due to krill harvesting (Constable et al., 2000).

Constable and Nicol (2002) outline an approach for using different scales of management units to integrate populations of target species with foraging grounds and environmental influences such as oceanography and metapopulation structure. For krill, catch limits are set for large areas, such as oceanic basins. However, subdividing into smaller areas can give a better estimate of the effect on foraging grounds of krill dependent predators. A management unit is self-contained with little external interference, and there are different units for different scales depending on the scale of the operation and the distribution and fragmentation of different populations. The krill yield model is assessed on the scale of the harvesting unit, comprising of different fishing grounds and a managed population, or metapopulation. A predator unit is smaller and is constrained by foraging grounds and prey population extent and location. Different predators will inadvertently have different foraging ranges and should be grouped in appropriate subsets, such as wide-ranging birds, or land-based predators. The authors also note that information acquired from different predator units can help differentiate between the effects of fishing versus the effects of the environment by using different fishing intensities relative to different foraging densities. Even though this has potential as part of the precautionary approach, again, fishing intensity should ideally be regulated so that the conservation objectives of CEMP are maintained.

Another important consideration is the idea of a 'trigger level', whereby the fishery cannot go beyond it, even if the catch limit is much higher, unless fishing effort is spread across a wider area or there is data to suggest that catches are sustainable at smaller scales (CCAMLR WEBSITE REF). For example, the current trigger level for the Scotia Sea is 620,000 tonnes of Krill within a wider catch limit of 5.6 million tonnes. This is an indication of how the precautionary approach can be implemented using a range of different management scales.

Studies that collect abundance and distribution data on krill dependent species can feed back into multispecies management of the krill fishery as part of an ecosystem-based approach. A paper estimating crabeater seal abundance suggested that there were between

0.7 and 1.4 million animals off the coast of East Antarctica, which accompanies a previous survey of the distribution and biomass of krill in the same area (Southwell, Paxton, Borchers, Boveng, & De la Mare, 2008). Likewise, gathering population data from different krill dependent species, along with environmental variables, can also be useful. In a study on populations of Adélie and chinstrap penguins on the Antarctic Peninsula, Trivelpiece et al. (2011) proposed an alternative hypothesis for fluctuations in population distributions. The 'sea-ice hypothesis' suggests that due to the large degree of warming in past decades, 'ice-loving' species such as Adélie penguins were being gradually replaced by 'ice-avoiding' species such as chinstrap penguins as sea ice melts in the area. The authors state that by linking penguin population abundance trends with krill biomass data over time, both penguin populations have been shown to respond strongly to the availability of krill, their main prey item. This is further shown by the increase of populations after exploitation of competing marine mammals and the current decrease of both populations, which is in contrast to the sea-ice hypothesis.

A study by Pinkerton and Bradford-Grieve (2014) applied a trophic analysis to a model of the Ross Sea food web in order to understand the trophic importance of different species based on their interactions with other groups. They make the point that investigating the effects of harvesting depends on the particular trophic characteristics of an ecosystem, and that measures of food web structure can assess risk to dependent species or the resilience of the ecosystem. This kind of data can then be used to make recommendations for research and monitoring as linkages can have different strengths and may be more important, and therefore need to be maintained.

One final point to note is the implementation of monitoring-feedback management to tackle the combined impacts on an ecosystem of harvesting and climate change (Fabra & Gascón, 2008). Also, in the case of the toothfish fishery there is the problem of Illegal, Unreported, and Unregulated (IUU) fishing, which can compromise fisheries management (Croxall & Nicol, 2004). In this regard management must be flexible and able to adapt in order to meet conservation objectives such as anticipating and mitigating long-term ecosystem change. Croxall and Nicol (2004) highlight the fact that different global forces that can potentially impact the Southern Ocean operate on different scales, from regional, local, and global scales, to reaction speeds of less than a year for management decisions, up to five years for science, and from decades to centuries in the case of climate change. Lastly, a study by Grant, Hill, Trathan, and Murphy (2013) investigated ecosystem services of the Southern Ocean in regards to the Krill fishery, and note that there is a lack of information on how components of the fishery represent ecosystem services that may be affected by harvesting. Ecosystem services are provisioning, regulating, nutrient cycling, and biodiversity maintenance, and are integral to the functioning of ecosystems. Research priorities in this area would therefore be highly beneficial.

As part of an ecosystem approach to fisheries management collecting information on dependent predators and other ecosystem and trophic level components is crucial to understanding the overall impact of harvesting. It is important also to take into considerations the issue of scale using different management units. And even though the entire ecosystem cannot be monitored, by using a precautionary approach the conservation objectives under the Convention area can be sustainably maintained (Hanchet et al., 2015).

Conclusion

Antarctica and the Southern Ocean are currently designated under the Antarctic Treaty as an area devoted to peace and science. However, marine harvesting has occurred throughout the history of Antarctica, and the exploitation of resources remains a very real concern. In this regard CCAMLR has developed both a precautionary and ecosystem-based approach to fisheries management in the Convention area. This is primarily to mitigate the effects of krill harvesting on marine ecosystems where krill is a key prey item, but also to sustainably manage the harvesting of other marine species under the conservation objectives set out in the Convention. To do so the CCAMLR Ecosystem Monitoring Programme aims to monitor key predators as indicators of the possible effects of removal of the target species on the ecosystem. CCAMLR must also incorporate further uncertainty into fisheries management due to climate change and other ecosystem stressors. The conservation of the Southern Ocean depends on the rational use of marine resources, and the continued development of an ecosystem approach to achieve robust science-based management decisions.

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